On the origin of complex memory effects in a granular gas

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We study in this theoretical work the physical origin of the emergence of surprisingly complex memory effects in a granular gas of identical rough hard spheres. The granular gas, usually defined as a low density set of particles that suffer instantaneous and binary inelastic collisions, is in this case driven by a stochastic force in the form of a white noise and the particles have uniform mass density [1].

If the stochastic force intensity suddenly changes, the system undergoes a time evolution through a series of non-hydrodynamic states, allowing for the emergence of memory effects. We show that, in this case, the granular temperature may display —for certain values of the relevant physical parameters— successive changes in the temperature trend. More specifically, this can occur when, after a sudden heat pulse at a given instant t_0, the white noise intensity ξ^2 is set so that the corresponding stationary granular temperature $T_\mathrm{s}(\xi^2)$ (i.e., the temperature for $t \to \infty$) coincides with the instantaneous granular temperature produced by the heat pulse $T(t_0)$, i.e., $T_\mathrm{s}(\xi^2) = T(t_0)$.

This kind of intricate memory effects are displayed in Fig. 1. As we can see, three consecutive changes in the time derivative show up here. In order to characterize the degree of complexity of this kind of memory effect, we define the magnitude

$$\mathcal{S} = \mathrm{sg}(T_\mathrm{s} - T_1)\frac{\min\{\mathcal{H}_1,\ \mathcal{H}_2\}}{\max\{\mathcal{H}_1,\ \mathcal{H}_2\}}, \tag{1}$$

where here T_1 is the temperature of the earliest extremum (maximum or minimum) and $\mathcal{H}_1 \equiv |T_1/T_\mathrm{s} - 1|$, $\mathcal{H}_2 \equiv |T_2/T_\mathrm{s} - 1|$ are the heights of the earliest and second earliest extrema. In Fig. 2 we observe, however, that at least in the case of uniform mass density particles this complex behavior is constrained to very narrow regions in the system parameter space. Out of the complex colored regions, the memory effect behavior resembles to the well known Kovacs effect [2], except that by comparison the magnitude of the effect is now giant [3].

In an accompanying work [4], we propose a laboratory set-up designed specifically for the production of a homogeneously excited granular gas. In this way, we intend to achieve the experimental detection of memory effects in a homogeneous granular gas eventually similar to the one described in the present work.

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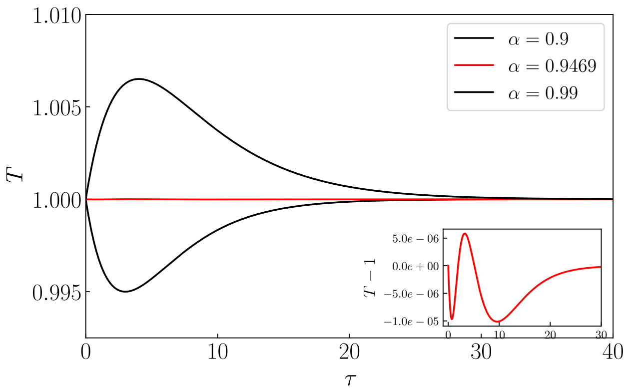

Fig. 1. Complex time evolution in the granular temperature after a sudden heat pulse from a white noise thermostat. α and β (here, $\beta = -0.65$) are the coefficients of normal and tangential restitution, respectively (see [1] for more detail).

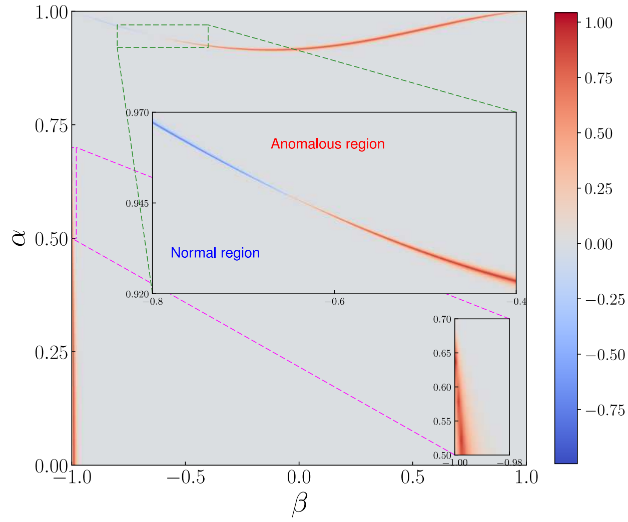

Fig. 2. Behavior of the memory effects complexity in the driven granular gas, when subject to a heating pulse. Two complex regions are detected, through definition of the magnitude $\mathcal{S}$ as it appears in Eq. (1).